Structural Optimization of Stubwing Structure of a Typical Light Transport Aircraft

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ABSTRACT

Weight targets and shortened time scales in the civil aircraft industries calls for an integration of advanced computer aided optimization methods into the overall component design process. Finite element based topology, sizing and shape optimization tools are typically used to obtain a first view on an optimal configuration for the structure-an initial design with optimal load paths. Next, the suggested configuration is interpreted to form an engineering design. The success of the above optimization scheme depends upon the proper interpretation of the results from these optimization methods. This paper deals with the topology and size optimization of stubwing structure of a typical light transport aircraft. By using these techniques a weight reduction of 15% was obtained. This methodology can be adapted to different Aerospace components.

Keywords: Topology Optimization, Size Optimization and Stubwing

1. INTRODUCTION

Optimization is a mathematical discipline that deals with the finding minima and maxima of functions, subjected to so called constraints (6). Optimization originated in the 1940's, when George dantzig used mathematical techniques for generating "programs' for military applications. Since then his "linear programming "techniques and their descendents were applied to a wide variety of problems in all disciplines.

Optimization is an act of obtaining best results under given circumstances. In design, construction and maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. Since the effort required or the benefit desired in any practical situations can be expressed as a function of certain decision variables, the optimization techniques can be used to obtain the best results. Conventional structural design processes are iterative in nature. In each step various relevant analyses are performed. The results obtained (displacements, stresses, etc.) are characterizing the performance of that particular design. Based on these results, the design is modified and reanalyzed. This loop has to be repeated until the desired output is obtained. The number of iterations depends on the experience of the designer and in complexity of the structure. Using structural optimization techniques the number of design iterations can be minimized to get the best results. This paper deals with structural optimization of stubwing structure of a typical light transport aircraft using topology and size optimization.

2. STRUCTURAL OPTIMIZATION TECHNIQUES

In the present work, Structural optimization has been carried out in two techniques viz., topology optimization and Size optimization.

2.1. Topology Optimization:

Topology optimization involves the optimal distribution of material within the structure. Topology optimization is used to find a preliminary structural configuration that meets predefined criteria. This type of optimization sometimes gives a design that can be completely new and innovative. Typically, the design process starts with a block of material called the design domain. The design domain is comprised of large number of candidate elements, and topology optimization process selectively removes from the domain those unnecessary elements. Topology optimization methods have been discussed in a large number of publications (1-5) and they can be categorized into two general approaches. The first approach, the assumed microstructure approach, tries to find the microstructure parameters (e.g. size and orientation of holes) of each designed element in a finite element model. The second approach assumes no microstructure, but rather heuristically designs the material properties (e.g. young's modulus and density) of each finite element directly to find optimal material distributions.

2.2 Size Optimization:

Size or parameter optimization typically uses element cross-sectional properties as design variables. These include parameters such as plate thickness, area and moment of inertia of a beam cross-section. Size optimization involves the modification of the cross-section or thickness of finite elements. The optimization is carried out by mathematical programming techniques with different objective functions for example maximum stiffness or minimum weight.

3. FINITE ELEMENT BASED STRUCTURAL OPTIMIZATION

Finite Element analysis has been carried out for 23 load cases. Out of this one critical load case was explained.

3.1 pre-processing:

The basic step in pre-processing is modeling of the component, which is to be analyzed. In this present work, analysis has been carried out for one critical load case. Geometric model of the Stubwing is shown in figure 1.FE model was prepared using commercially available pre and post processor called Altair Hypermesh (7). The surfaces are then meshed using shell elements (QUAD4, TRIA3). Bolts and stringers are modeled using beam elements. The Stubwing consists of spars, ribs, channels, stringers and skins etc, are made of Aluminium. Steel has been used for bolts.
The model was constrained at stubwing-fuselage attachment points as shown in figure 2.

3.2 Structural Optimization:

Structural Optimization was carried out in two stages. In the first stage, the structure was subjected to topology optimization. In the second stage, the structure optimized using topology optimization was subjected to size optimization. The analysis was carried out by using commercially available FE solver Altair Optistruct.

3.2.1Topology Optimization

The present work adopts the density approach. In general, topology optimization process can be divided into four main phases, which are as follows:

Phase 1-Requires definition of package space and the designable and non-designable portions. Designable portion is the web region of the front and rear spars as shown in the figure 3 and remaining part of the structure is the non-designable portion.

Phase 2-Requires definition of design optimization problem. The global objective, load cases and constraints are defined in this phase. In this case objective is to minimize the global compliance of the structure, subjected to a minimum volume fraction constraint.

Definition of Topology Optimization problem is as follows:

Design variable - Density of the material

Design objective - Minimization of the compliance (The compliance is the strain energy of the structure and can be considered as reciprocal measure for the stiffness of the structure.)
Design constraint - volume fraction target of 0.3 (total volume at current iteration – initial non-design volume)/initial design volume
Phase 3-Covers post processing of the results and visualization of the idealized shape
Phase 4- Modifications of the structure based on topology optimization results, taking into account for various design constraints.
Results of topology optimization:
The stress before topology optimization is shown in figure 4. The density plot obtained from analysis with volume fraction 0.3 is shown in figure 5.
The blue color region in the plot shows the density in that region of the model is very less, which indicates the material in that area can be completely removed (making cutouts) or the minimum thickness in that area is retained. The red color region indicates that material is essentially required. Depending upon the density plot, new cutouts were introduced to reduce the weight of the structure. The web with new cutouts is shown in the figure 6. The von mises stress plot for the Spars after topology optimization is shown in figure 7.

3.2.2 Size Optimization

The model is subjected to size optimization to get the optimized thickness for the webs and the flanges of all components (spars, ribs, channels and skin) of stubwing. The structure after topology optimization, subjected to size optimization to set optimized thickness.
Definition of Size Optimization problem is as follows:
Design variable - Thickness of the components.
Design objective - Minimization of the Mass.
Design constraint - Stress
The loads and the boundary conditions are the same as those are used for topology optimization. In size optimization the thickness of the components are treated as variables. As the thickness of the component was reduced, the weight of the components is also reduced.
Results of size optimization
Von mises stress plot for the stubwing structure after size optimization is shown in figure 8. The stresses are within the limits and hence the optimization carried out for the Stubwing structure is safe according to design point of view.

4. CONCLUSION

The present work illustrates how topology and sizing optimization tools can be used in the design of aircraft components. The technology has been successfully used in an industrial environment with short industrial time scales and it is proved to be able to provide efficient strength and stability component designs.
In the present work the initial weight of the structure was 36.5 kg. By the combined application of Topology and Size optimization as resulted in weight reduction of nearly 6 kg (i.e. final weight of 30.5kg) of the structure.

5. ACKNOWLEDGEMENT

I express my sincere thanks to **Dr. A.R. Upadhya, Director, National Aerospace Laboratories**, and **Dr. M. N. Sathyanarayana, Head, Technical Secretariat**, for allowing me to do the work in NAL.
I express my sincere thanks to **Mr. Chidananda, Head** and **Dr. H.N.V. Dutt, joint Head**, **C-CADD Division, National Aerospace Laboratories, Bangalore** for allowing me to do the work in C-CADD division, NAL.
I wish to express my profound sincere gratitude to my guide **Mr. Abbani Rinku, Scientist, C-CADD Division, N.A.L, Bangalore**, for his excellent and valuable guidance, advice and encouragement in carrying out the work.
I wish to thank my internal guide **Dr. D. Ramesh Rao, Asst. Professor, Department of Mechanical Engineering, BIET, Davangere**, for his valuable suggestion throughout my work.

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7. FIGURES

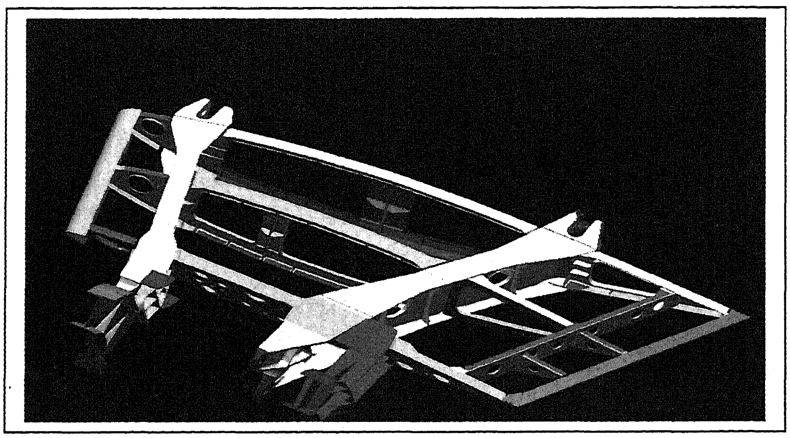

Figure 1. Geometric model of Stubwing

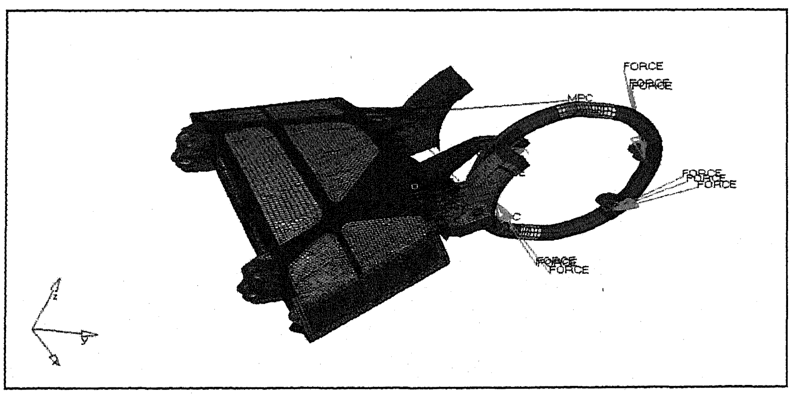

Figure 2. FE model with boundary conditions

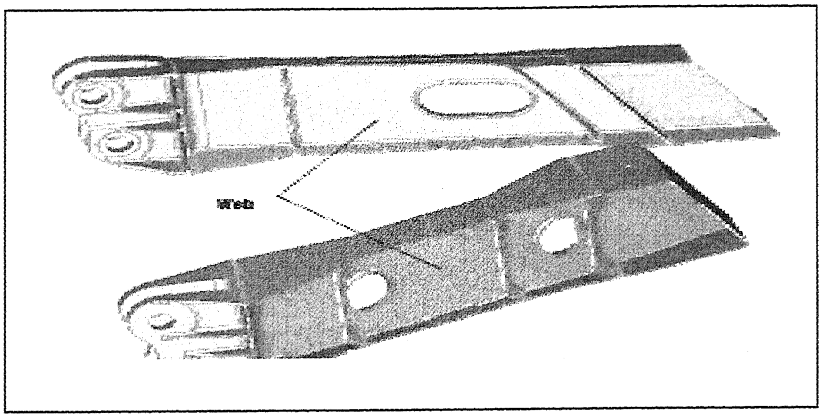

Figure 3. Designable and non-designable regions.

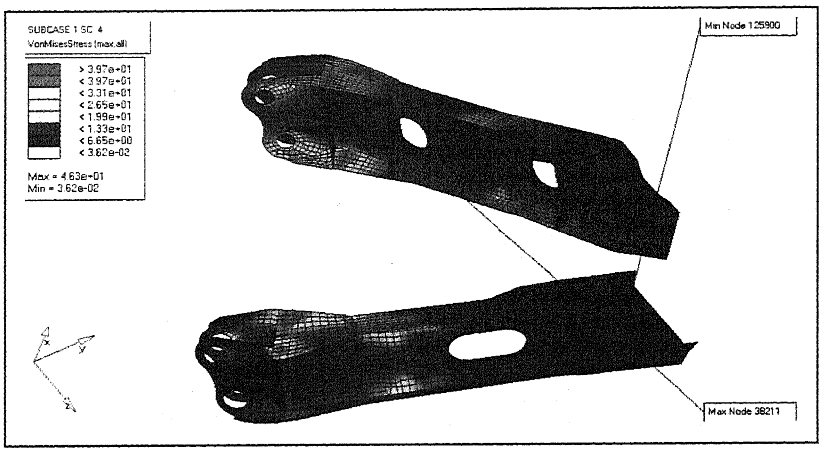

Figure 4. Stress plot of spars before optimization

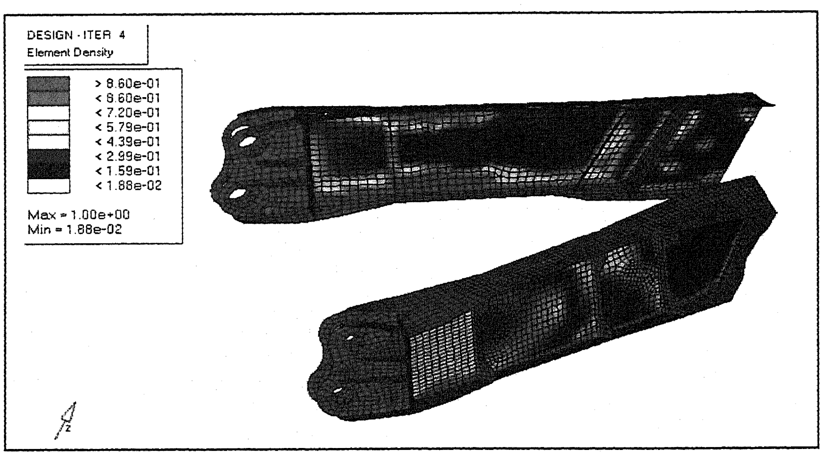

Figure 5. Element-density plot for volume fraction

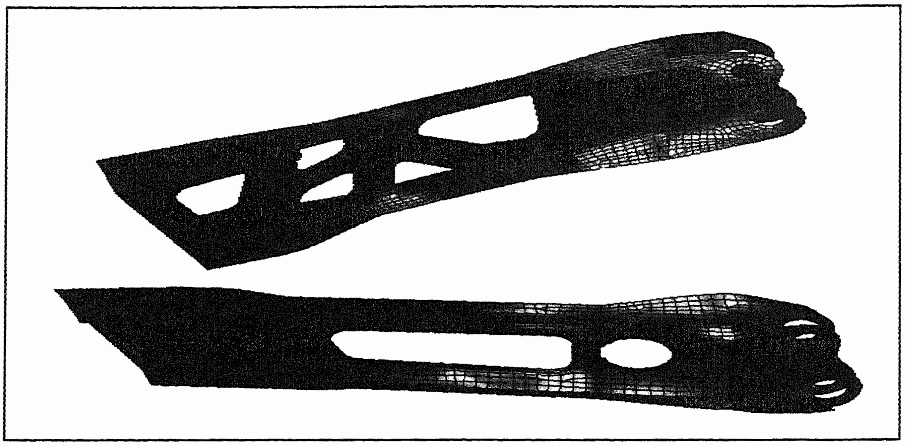

Figure 6. Web with new cutouts after topology optimization

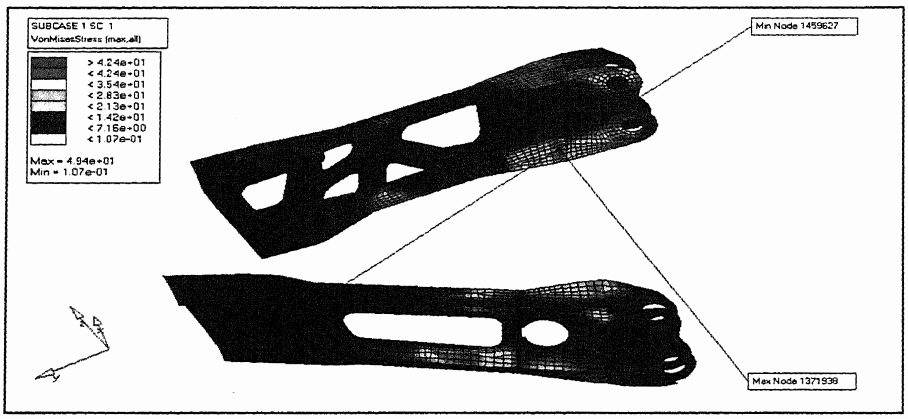

Figure 7. Von mises Stress plot for the spars after topology optimization

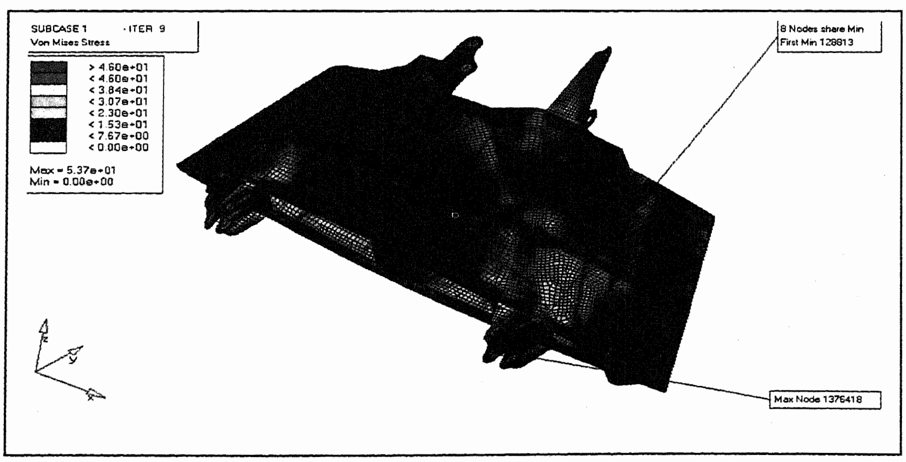

Figure 8. Stress plot after size optimization